Predicting Runoff and Sediment Yield from a Stiff-Stemmed Grass Hedge System for a Small Watershed

A. Rachman, S. H. Anderson, E. E. Alberts, A. L. Thompson, C. J. Gantzer

Abstract. *Grass hedges planted at regular intervals on the landscape offer many opportunities to reduce runoff and sediment from leaving fields. Objectives of this study were (1) to evaluate the ability of the WEPP watershed model to simulate grass hedge system effects of sediment trapping (TE), bench terracing (BT), and variable effective soil hydraulic conductivity (HC) on simulated hillslope runoff and sediment yield, and (2) to model the effects of measured effective hydraulic conductivity (K_{eff}) values from a grass hedge management system by comparing predicted runoff and sediment yield values to those measured in a small watershed over an 11-year period. The study was conducted on a 6.6 ha watershed located in the deep loess hills region of southwestern Iowa. Narrow grass hedges of predominantly switchgrass (*Panicum virgatum*) were planted at 15.4 m intervals in 1991. The WEPP model simulated greater reductions in runoff (9%) and sediment yield (58%) from BT compared to TE and HC effects. Combination of all three effects gave the highest reductions in runoff (22%) and sediment yield (79%) compared to individual effects or any combination of two effects. The watershed model did not adequately simulate slope length reduction effects from the grass hedges. Runoff (r^2 = 0.78) and sediment yield (r^2 = 0.75) were comparable to observed data when measured K_{eff} values for grass hedge, row crop, and channel areas were used as input data. Measured K_{eff} data from grass hedge, row crop, and channel areas should be used for improved runoff and sediment yield predictions.*

Keywords. *Bench terracing, Effective hydraulic conductivity, Sediment trapping, Switchgrass hedges, WEPP model.*

Grass hedge systems have received attention because they can control runoff and sediment yield from a cropped watershed (Dabney et al., 1993). Dabney et al. (1993) defined grass hedges as narrow strips of stiff-stemmed, erect grasses. Grass hedges require less land than grass buffers. These hedges capitalize on, rather than minimize, the formation of berms with deposited sediment upslope and within the hedges. Several benefits of grass hedge systems have been observed, including delayed and reduced surface runoff (Gilley at al., 2000), trapped sediments (Meyer et al., 1995; Raffaelle et al., 1997; McGregor et al., 1999; Gilley et al., 2000), and facilitated benching of sloping cropland from soil movement by tillage operations (Dabney et al., 1999). The hedges, along with waterborne crop residues that lodge in the upslope edge of the grass, slow runoff velocity and create ponded water upslope from the hedges. This phenomenon enhances the deposition of transported sediments in the ponded areas, which modifies the surface elevation between hedges (Dabney et al., 1995). Deposition of sediment upslope of the hedges increases the density of soil as finer particles clog the pores (Rachman et al., 2004).

Mathematical models have been used to predict runoff and erosion from sloping land with varying results (Morgan and Quinton, 2001). These models can be used to assess the extent of the runoff and soil erosion, identify key areas and processes involved, and test suitable solutions to the problem. Because on-site measurement and monitoring of runoff and soil erosion are expensive and time consuming, models are often used as tools in making runoff and erosion assessments. Empirical models, such as the Universal Soil Loss Equation (USLE), have received widespread use and acceptance because less data and fewer computations are required than process-based models (Tiwari et al., 2000). However, empirical models were not designed to accommodate the spatial and temporal variability in the ongoing natural processes (Tiwari et al., 2000).

Process-based models combine the effects of erosion mechanics with other processes that affect conditions related to soil erosion, such as hydrology and plant growth (Foster and Lane, 1987). The approach takes into account temporal changes in crop growth, residue cover, soil water, and other soil characteristics, which may increase the accuracy of runoff and erosion predictions. The Water Erosion Prediction Project (WEPP) model is a continuous simulation computer program designed to predict the impacts of cropland, range-

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land, and forest on runoff and soil loss on a daily basis (Flanagan and Nearing, 1995). The model can be used to predict watershed runoff and sediment yield (Ascough et al., 1997). The application of WEPP requires that hillslopes be delineated and channels identified (Baffaut et al., 1997).

The watershed version of the WEPP model has been used to predict runoff and sediment yield from rangeland management (Tiscareno-Lopez et al., 1994) and from cultivated watersheds (Liu et al., 1997; Cochrane and Flanagan, 1999; Ghidey et al., 2001; Alberts et al., 2001). However, few studies have evaluated the performance of the WEPP model on small watersheds with grass hedge systems. Studies have indicated that predicting runoff using a single average value of saturated hydraulic conductivity produces inadequate model predictions (Gómez et al., 2001; Blanco-Canqui et al., 2002).

The objectives of this study were to (1) evaluate the performance of the WEPP watershed model in simulating the grass hedge specific effects of sediment trapping (TE), bench terracing (BT), and changes in soil hydraulic conductivity (HC) on simulated hillslope runoff and sediment yield; and (2) model the effects of measured effective hydraulic conductivity (K_{eff}) values from a grass hedge management system by comparing predicted runoff and sediment yield values to those measured in a small watershed over an 11-year period.

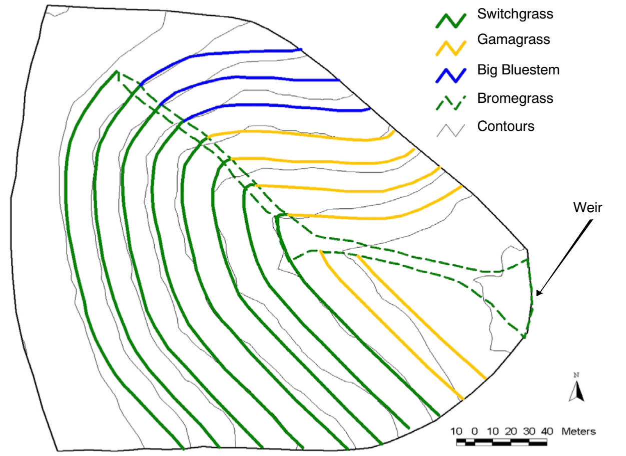

Figure 1. Schematic of small 6.6 ha watershed near Treynor, Iowa, with contours and locations of planted hedges.

Materials and Methods

Watershed Characteristics

The study was conducted on a 6.6 ha watershed at the USDA-ARS National Soil Tilth Laboratory Deep Loess Research Station near Treynor, Iowa. The watershed consisted of four soil types, with the predominant soil being Monona silt loam (fine-silty, mixed, superactive, mesic Typic Hapludolls). Other soil types found in the watershed were Ida silt loam (fine-silty, mixed, superactive, calcareous, mesic Typic Udorthents), Napier silt loam (fine-silty, mixed, superactive, mesic Cumulic Hapludolls), and Dow silt loam (fine-silty, mixed, superactive, calcareous, mesic Typic Udorthents). Original slopes within the watershed were 2% to 4% for ridges and valleys and 12% to 16% for mid-slopes (Grossman et al., 1992). Surface soils have silt loam textures and are classified as highly erodible land (HEL; Rachman et al., 2004).

Runoff and sediment yield from the watershed had been measured since 1975. Beginning in 1991, the first seven grass hedges were established along the southern and western portions of the watershed (fig. 1). The measured distance between two hedges was 15.4 m to accommodate 16 rows of corn. Vertical intervals between hedges ranged from 0.6 to 2.5 m following the range in slope between hedges of 5% to 16.5%. Currently, the width of the hedges is between 0.75 and 1 m. The total length of grass hedges established in the watershed was about 2400 m, which covered about 4% of the watershed area, with another 2% of the area for grass waterways and access areas. Grass species used for the hedges was predominantly switchgrass (*Panicum virgatum* L.). Other grasses were big bluestem (*Andropogon gerardii* Vitman), eastern gamagrass (*Tripsacum dactyloides*), and miscanthus (*Miscanthus sinenses purpurascens*).

Precipitation was measured by a recording gauge located near the outlet of the watershed. Runoff was measured with a broad-crested V-notch weir with a stage recorder located at the watershed outlet (Kramer et al., 1999). Samples were collected with an automatic pumping sampler during runoff events to measure sediment concentrations. The unit was equipped with a sensor, positioned at about 3 cm above the bed, to automatically activate the sediment sampler when flow reached the sensor. Sediment yield was computed using measured sediment concentrations and representative runoff volumes, which were summed by runoff event. Sediment yield was divided by the watershed area to compute unit area values (Mg ha^{-1}).

WEPP Input Files

The WEPP watershed model for Windows was used to predict runoff and sediment yield (Flanagan and Frankenberger, 2002). This version allowed partitioning of the drainage area into several overland flow elements (OFEs) to define grass hedges and representative row crop areas that included different hydraulic properties. The WEPP watershed model requires hillslope information, climate, cropping and management, soil, and channel files.

Climate

Measured daily precipitation parameters were read into the climate file, and the remainder of the climate parameters were generated. A previous study indicated that the model was highly sensitive to precipitation depth, duration, and the ratio of the maximum intensity over the average storm intensity, but not to the ratio of time to peak over duration (Tiscareno-Lopez et al., 1993). CLIGEN version 4.3, the stochastic weather generator included with WEPP, was used to generate the remainder of the climate file using weather parameters from the Oakland, Iowa, climate station, located about 20 km northeast of the watershed. Runoff and sediment yield were computed on an event basis from 1975 to 2002. For this study, only simulation results from 1992 to 2002 were used for comparison with measured data. The analyses of runoff and sediment yield were limited to events that occurred between 1 April and 31 October.

Cropping and Management

The study area was under conventionally tilled continuous corn from 1965 to 1996, no-till soybean from 1997 to 1999, and a no-till corn-soybean rotation from 2000 to 2002. The WEPP model contained default data for continuous corn, no-till soybean, no-till corn-soybean rotation, and big bluestem grass. Default data were modified to include data for tillage equipment and date of use, planting date, type of crop, cultivation date, harvest date, and residue management. Minor adjustments were made for some tillage parameters (depth, roughness, intensity, ridge height, and ridge spacing) and initial conditions (bulk density, canopy cover, frost depth, and residue cover). Because data for switchgrass were not available in the WEPP database, the default data for big bluestem grass were used to simulate grass hedges.

Preliminary evaluation of simulated erosion profiles along the hillslope showed excessive estimates of soil loss below the hedges. Because the primary advantages of hedges are to reduce runoff (volume and velocity) and trap detached sediment, lower soil losses below the hedges were expected based on observations with stiff-stemmed grass hedges (McGregor et al., 1999; Blanco-Conqui et al., 2004a, 2004b, 2006) and filter strips (Dillaha et al., 1989; William et al., 1989; Robinson et al., 1996). Rill parameter values in the crop management files were adjusted to help correct this problem. Adjustments were made for each crop management (continuous corn, no-till soybean, no-till corn-soybean rotation, and grass hedge) by changing the rill spacing until a reasonable soil loss profile was attained. The initial rill width was set to 2.5 cm in all crop management files since this parameter setting allowed the erosion profile along the slope to more accurately reflect observations. Rill spacing for continuous corn, no-till soybean, no-till corn-soybean rotation, and grass hedges was set at 2.5 cm. The rill type was set to "temporary" for all crop management files. It is recognized that this rill spacing is smaller than realistically found in the field. It is speculated that the model may use excessively large runoff velocities immediately below the hedge, which will affect shear stress and subsequent sediment detachment. It is recommenced that future research address this issue.

Slope

The digital elevation model (DEM) of the watershed was created based on a survey conducted in 1999 to measure changes in soil elevation due to the grass hedge system. The survey used a real-time kinematic (RTK) GPS approach (Clark and Lee, 1998). The vertical accuracy of the RTK GPS ranged from 2 to 5 cm, and horizontal accuracy can be as close as 1 to 2 cm (Clark and Lee, 1998). The cell size of the created DEM was 0.484 m, producing a rectangular grid with 592 rows and 600 columns. The lowest elevation was 342 m, and the highest elevation was 375 m.

Ten hillslopes and four channels were delineated in the watershed based on DEMs (fig. 2). The main channel extended from the watershed outlet to the middle of the watershed, and two other channels (C-1, C-2) fed the main channel. The main channel was further segmented into two subchannels (C-3, C-4) to allow the model to establish four hillslopes: two hillslopes (H-1, H-2) on the south side, and two others (H-9, H-10) on the north side of the main channel. Three hillslopes (H-6, H-7, H-8) were delineated from channel 1, and three other hillslopes (H-3, H-4, H-5) were delineated from channel 2. Therefore, a total of ten hillslopes and four channels were created. Characteristics of each hillslope are presented in table 1. A ground check was conducted to ensure that the delineated subwatersheds and channels matched field conditions. Each of the hillslopes was partitioned into several OFEs representing the slopes between and within grass hedges. Slope gradient, length, width, and aspect were computed from the DEM data.

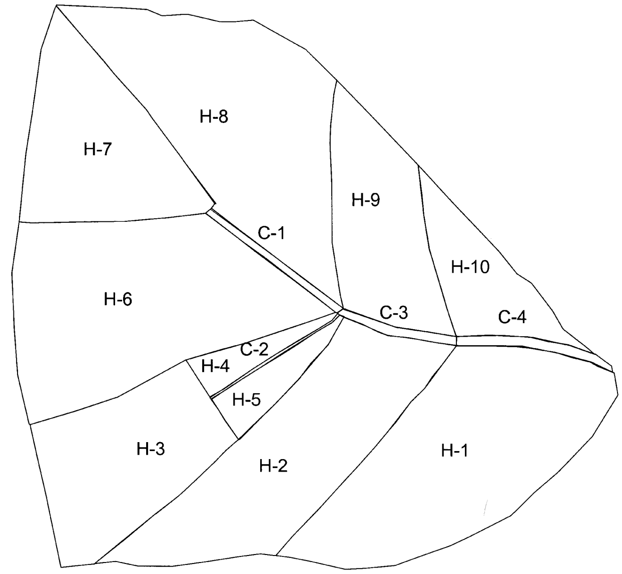

Figure 2. Delineated hillslopes (H) and channels (C) in the 6.6 ha watershed near Treynor, Iowa.

Soil

Soil characteristics, including percent sand, percent clay, organic matter content, rock fragment fraction, and cation exchange capacity, were obtained from measured soil samples and from the detailed soil map of the watershed (scale 1:1700; Larry Kramer, personal communication). Albedo was obtained from the USDA-NRCS STATSGO database (www.ncgc.nrcs.usda.gov/products/datasets/statsgo). Initial saturation was assumed to be at field capacity for each of the soils. The interrill erodibility (K_i) and rill erodibility (K_r) values were estimated with the equations provided by the model (Flanagan and Nearing, 1995) along with other measured soil physical property data. These values were 4,499,334 kg s m^{-4} and 0.0073 s m^{-1}, respectively. The critical shear stress (τ_c) input value selected was 3.5 Pa based on soil and crop management information. These selected values were similar to measured values for this soil. Model calibration was conducted, altering the soil erodibility parameters and comparing simulated results with measured sediment yield data from the watershed. Calibration was done using 1992 and 1993 data.

The K_{eff} values of the grass hedge and row crop areas were calculated from measured data (Rachman et al., 2004). Six

Table 1. Slope length, gradient, and area of each hillslope profile in the watershed.

Hillslope Profile	Length (m)	Gradient (%)	Area (ha)
1	104	3 - 5	1.07
2	150	5 - 8	0.89
3	102	3 - 7	0.62
4	15	5 - 6	0.07
5	23	7 - 8	0.14
6	145	5 - 9	1.13
7	110	5 - 9	0.61
8	110	4 - 9	1.13
9	93	6 - 7	0.51
10	47	4 - 7	0.27

replicate soil cores were removed in June 2001 from four 10 cm soil depths (0 to 40 cm) in the row crop and grass hedge areas for measurement of saturated hydraulic conductivity. The four depths were integrated using the standard approach to obtain effective saturated hydraulic conductivity (Blanco-Canqui et al., 2002) for the two areas. Measured values were 34 and 5.1 mm h^{-1} for the grass hedge and row crop areas, respectively.

Channel

Channel parameters, except for the size of the channel and surface cover, were identical for all channels. Smooth bromegrass (*Bromus inermis*) was grown in channels C-1, C-3, and C-4; soil parameter values from the grass hedges were used for these channels. Soil parameter values assigned for C-2 were the same as those used for the cropped areas on the hillslopes, because this channel was row cropped.

Evaluation of Grass Hedge System Components

The first objective was to evaluate the performance of the WEPP watershed model in simulating the effects of sediment trapping (i.e., trapping efficiency of the grass hedge as a filter for sediment and a barrier to reduce runoff velocity), saturated hydraulic conductivity as affected by the hedges on simulated runoff and sediment yield, and bench terracing (i.e., natural bench terracing from sediment trapping and soil movement by tillage). These tests were not compared to measured data due to the difficulty and necessity for a large laboratory-scale approach. However, if the model cannot simulate runoff and sediment yield for these three effects at the hillslope scale, then it would not be expected to simulate the grass hedge system at the watershed scale. Eight scenarios of different system components were simulated to achieve this objective (table 2). For the trapping efficiency of the grass hedges (TE), "Included" indicates that a warm season grass was grown in the hedge positions, while "Not included" indicates that continuous corn was grown in the hedge positions. For the hydraulic conductivity parameter (HC), "Uniform" indicates that hydraulic conductivities for grass hedge and row crop positions were the same (5.1 mm h^{-1}), while "Non-uniform" indicates that hydraulic conductions were different (34 mm h^{-1} for grass hedge and 5.1 mm h^{-1} for row crop positions). For the bench terracing (BT), "Included" indicates that slopes measured in 1999 after seven years of grass hedges were used, while "Not included" indicates that original slopes for the hillslopes were used. All other model parameters were kept constant.

Five-year (1992-1996) simulations were conducted by running the WEPP hillslope model on a single hillslope. Slope length and gradient for the control (continuous corn, uniform slope, no hedges, and uniform K_{eff}) were 100 m and 8%, respectively. Another set of simulations was conducted with the hillslope segmented into ten OFEs (maximum allowed in WEPP). These simulations were used to predict the effects of TE, HC, and BT. Slope length between hedges was 15.5 m, and the width of each hedge was 1 m. Slope length (terrace spacing) from the slope summit to the first hedge was 33 m. The slope gradients for each OFE, read from the summit to the bottom slope, were 3%, 6%, 6%, 6%, and 7%. A nearly 0% slope was used within the 1 m hedges between regular slope lengths (terrace spacings). Precipitation ranged from 574 mm in 1994 to 1334 mm in 1993. Crop management was conventionally tilled continuous corn for these comparisons.

Table 2. Grass hedge system components simulated with the WEPP model.

System Components	Grass Hedge	Hydraulic Conductivity	Bench Terracing
Control	Not included	Uniform	Not included
TE[a]	Included	Uniform	Not included
HC[b]	Not included	Non-uniform	Not included
BT[c]	Not included	Uniform	Included
BT+HC	Not included	Non-uniform	Included
TE+BT	Included	Uniform	Included
TE+HC	Included	Non-uniform	Not included
TE+HC+BT	Included	Non-uniform	Included

[a] TE = trapping efficiency of grass hedges; "Included" indicates a warm season grass was grown in the hedge positions, "Not included" indicates continuous corn was grown in the hedge positions.

[b] HC = hydraulic conductivity; "Uniform" indicates hydraulic conductivities for grass hedge and row crop positions were the same (5.1 mm h^{-1}), "Non-uniform" indicates hydraulic conductivities were different (34 mm h-1 for grass hedge and 5.1 mm h-1 for row crop positions).

[c] BT = bench terracing; "Included" indicates slopes measured in 1999 after seven years of grass hedges were used, "Not included" indicates original slopes for the hillslopes were used.

Additional simulations were performed to evaluate the sensitivity of the WEPP watershed model to different slope length and gradient configurations between hedges. These simulations were conducted using the combined system components (TE+HC+BT) with conventionally tilled continuous corn for one year (1993). This year was chosen because it had the highest precipitation and runoff for the five-year period (1992-1996). The total slope length was 66 m, with 62 m under row crop management and 4 m under grass hedge. Slope lengths between hedges were set to 15.5, 31.0, and 62.0 m. For each slope length, slope gradients of 4%, 6%, and 8% were evaluated, with all other parameters (rainfall, soil erodibility, and crop) remaining constant. The sensitivity of runoff and sediment yield predicted by the model to slope length and gradient was determined using the following equation (McCuen and Snyder, 1986):

$$\mathrm{SN} = \frac{\Delta O}{\overline{O}} \Big/ \frac{\Delta I}{\overline{I}} \tag{1}$$

where SN is normalized sensitivity coefficient, ΔO is change in output variable, ΔI is change in input variable, $\overline{O}$ is average output value, and $\bar{I}$ is average input value.

Evaluation of Keff on Watershed Runoff and Sediment Yield

The second objective was to model the effects of measured K_{eff} values from a grass hedge management system by comparing runoff and sediment yield predictions to those measured over an 11-year period (1992-2002). Measured K_{eff} values from hedge areas (34.0 mm h^{-1}) and from row crop areas (5.1 mm h^{-1}) were used to model the effects of hydraulic conductivity within the watershed (Rachman et al., 2004). Analyses of model outputs were conducted on an event basis.

Two quantitative methods were used to evaluate the performance of the model: regression analysis (r^2) and model efficiency analysis (ME; Nash and Sutcliffe, 1970). Model efficiency was calculated by:

$$\mathrm{ME} = 1 - \frac{\sum_{i=1}^{n}(Q_{mi} - Q_{ei})^2}{\sum_{i=1}^{n}(Q_{mi} - Q_m)^2} \quad (2)$$

where ME is the efficiency of the model, Q_{mi} is the measured value of event i, Q_{ei} is the predicted value of event i from the model, and Q_m is the mean of measured event values. Model efficiency values ranged from negative to positive. Model efficiencies near one indicate good agreement between predicted and measured values, and decreasing values indicate less agreement between the two. A negative model efficiency value indicates that the average measured value is a better estimate than the model prediction.

Research Assumptions

Assumptions made to conduct the simulations with the WEPP watershed model included:

1. Rainfall was assumed to be distributed uniformly over the 6.6 ha watershed; therefore, only one climate input file was created.
2. Slope gradients between hedges and the soil properties were considered constant and not time variant. Slope properties used for the simulation were generated from elevation data collected in 1999 after seven years of hedge development. Soil hydraulic properties were measured in 2001.
3. The backwater phenomena observed by Dabney et al. (1999) is not represented in the WEPP model. The backwater effect is important in modeling results from confined erosion plots. However, it is assumed to be less important in a field because hedges were not planted on the perfect contour and runoff was not confined.
4. The deposition zone, which had the lowest hydraulic conductivity (1.4 mm h^{-1}; Rachman et al., 2004) as compared to the grass hedge and row crop areas, was not considered. Several preliminary simulations indicated that the deposition zone had minor effects on runoff and sediment yield predictions. Including the deposition zone increased runoff prediction by 0.22% ±0.19% and reduced sediment yield by 0.35% ±0.31% for a 130 mm precipitation event. Therefore, excluding the deposition zone should not significantly affect runoff and sediment yield predictions.

Results and Discussion

Grass Hedge System Effects

Simulated effects of trapping efficiency (TE), changes in K_{eff} in the grass hedge areas (HC), and bench terracing (BT) on runoff and sediment yield as individual and combined effects are shown in figure 3; these are simulated, not measured values. Percent reductions in simulated runoff and sediment yields relative to continuous corn without a grass hedge system are illustrated. BT gave the highest reductions in runoff and sediment yield (9% and 58%) as compared to TE (3% and 36%) and HC (7% and 1%). Increasing K_{eff} (from 5.1 to 34 mm h^{-1}) in the grass hedge areas was effective in simulating reduced runoff. The simulated BT+HC combination reduced predicted runoff and sediment yield by 16% and 65%, respectively, compared to the control, while the TE+HC combination was less effective, predicting a 13% reduction in runoff and a 42% reduction in sediment yield. As expected, the combination of the three system components (TE+HC+BT) gave the highest reduction in simulated runoff and sediment yield. Results show that the individual BT effect (changes in slope) had the most impact on sediment yield and runoff; the BT effect occurs in the grass hedge system from sediment deposition, soil movement by tillage, and subsequent reduction in slope steepness. Higher hydraulic conductivity associated with the grass hedges was an important system component factor in reducing predicted runoff, but not sediment yield. Previous studies have shown the importance of including accurate hydraulic conductivity data for runoff predictions (Risse et al., 1994; Blanco-Canqui et al., 2002). Results indicate that the WEPP model simulates responses for individual and combined components of a grass hedge system. Thus, these simulation results increase confidence that the model may be appropriately applied to a watershed with a grass hedge system.

Before addressing the second objective, additional simulations were performed to evaluate the sensitivity of the WEPP watershed model to different slope length (terrace spacing) and gradient configurations between hedges. Results from simulations of the different slope length (terrace spacing) and gradient configurations on runoff and sediment

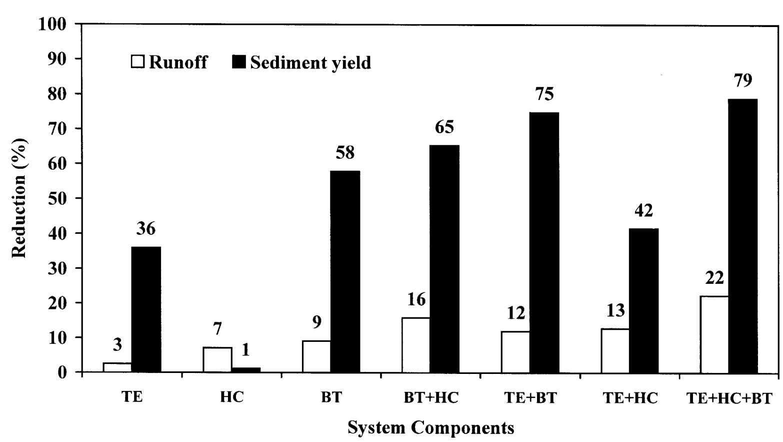

Figure 3. Simulated runoff and sediment yield reductions for grass hedge system components relative to the control where the entire hillslope was planted to conventionally tilled continuous corn.

Table 3a. Influence of slope length (terrace spacing) and gradient on simulated runoff and sediment yield from the WEPP model.

Slope Length Between Hedges (Terrace Spacing)	4% Slope Gradient		6% Slope Gradient		8% Slope Gradient	
	Runoff (mm)	Sediment Yield (Mg ha^{-1})	Runoff (mm)	Sediment Yield (Mg ha^{-1})	Runoff (mm)	Sediment Yield (Mg ha^{-1})
15.5 m	42	3.9	47	5.1	50	6.0
31.0 m	43	4.1	47	5.2	49	6.0
62.0 m	43	4.1	47	5.2	49	6.1

Table 3b. Sensitivity analysis of slope length (terrace spacing) and gradient.

Parameter	Runoff	Sediment Yield
Slope length (terrace spacing)	0.00	0.02
Slope gradient	0.22	0.61

yield are shown in table 3. Runoff and sediment yield were sensitive to slope gradient, with normalized sensitivity coefficients of 0.22 and 0.61, respectively (table 3). Simulated runoff and sediment yield were much less sensitive to differences in slope length (terrace spacing) among the three length scenarios evaluated; sediment yield would probably be low due to no changes in simulated runoff. The model simulated similar values whether there were four 1 m wide hedges spaced evenly along the 66 m hillslope profile or a 4 m wide hedge at the bottom of the slope with 62 m of conventionally tilled corn above.

Evaluation of Keff at Watershed Scale

Results for WEPP-predicted runoff and measured runoff on an event basis for the 1992-2002 period for two K_{eff} conditions are shown in figure 4. One simulation was conducted using a uniform K_{eff} value of 5.1 mm h^{-1} for all locations within the watershed. The other simulation used two different values: 5.1 mm h^{-1} for row crop areas and 34.0 mm h^{-1} for grass hedge and channel areas based on measurements taken in 2001 (Rachman et al., 2004).

Predicted runoff using uniform K_{eff} values was generally higher than measured runoff, as indicated by a regression slope of 1.23. The coefficient of determination (r^2) for this relationship was 0.72, with a modeling efficiency (ME) of 0.32. The fact that the slope of the regression line is greater than one when using uniform K_{eff} indicates that the model is biased upwards, although this bias is not clearly indicated in figure 5 since the prediction errors are heteroskedastic. It is noteworthy that at near-zero measured runoff, substantial runoff (greater than 20 mm) was predicted by the uniform K_{eff} parameter for four events (figs. 4 and 5). The prediction error plot (predicted minus measured runoff) illustrates overprediction for runoff events less than 5 mm and greater than 20 mm (fig. 5).

Predicted runoff using nonuniform K_{eff} values agreed more closely with measured runoff values than when using uniform Keff values. The slope of the regression equation was not significantly different from one, with a coefficient of determination (r^2) of 0.78 and a modeling efficiency (ME) of 0.72. For the seven runoff events with measured values >20 mm, the simulation with different K_{eff} values reduced the average error by about 50%. Two events with measured runoff >50 mm were also evaluated: one event was in the middle of June 1998, and the other was in early August 1999. Almost no change in predicted runoff occurred during the June event for the two simulations, probably because rainfall that preceded the runoff event decreased or eliminated differences in antecedent soil water content. For the August event, there was a large reduction in predicted runoff between the two simulations, probably because the antecedent soil water content for the hedge and channel areas was low from lack of rainfall during the prior month. Results illustrate the effects of the measured differences in K_{eff} values between grassed and row crop areas and the importance of using appropriate K_{eff} values in predicting surface runoff from a watershed containing perennial grasses.

WEPP-predicted and measured sediment yields on an event basis for the 1992-2002 period for two K_{eff} conditions are shown in figure 6. In the first condition, the soil hydraulic conductivity (K_{eff} = 5.1 mm h^{-1}) was treated uniformly for the watershed, while in the second condition, the hydraulic conductivity (K_{eff} = 34.0 mm h^{-1}) was higher for the grass hedges and channel areas.

Predicted sediment yield using uniform K_{eff} values was higher than measured values, as indicated by a regression

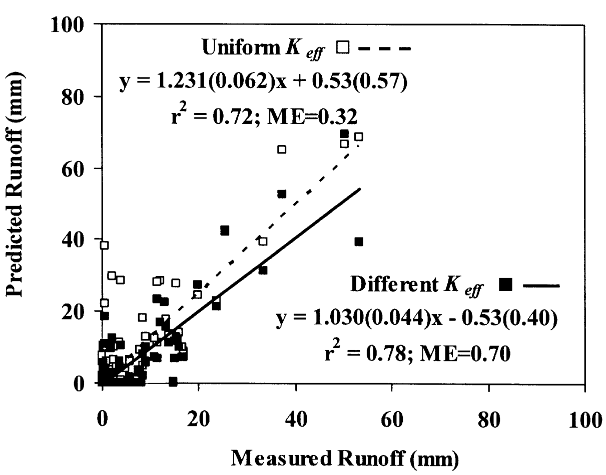

Figure 4. WEPP-predicted runoff using uniform K_{eff} (5.1 mm h^{-1}) and different K_{eff} (grass hedge = 34 mm h^{-1} and row crop area = 5.1 mm h^{-1}) vs. measured runoff. Values in parentheses are standard errors of parameter estimates.

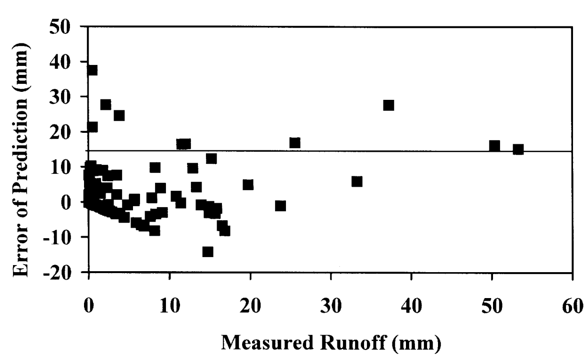

Figure 5. Error of prediction (predicted minus measured runoff) using uniform K_{eff} vs. measured runoff by event.

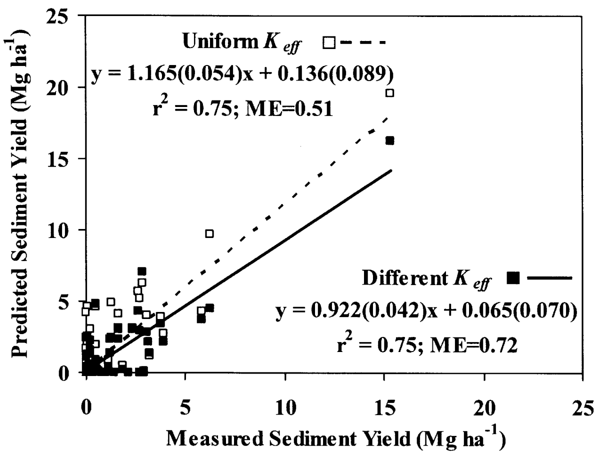

Figure 6. WEPP-predicted sediment yield using uniform K_{eff} (5.1 mm h^{-1}) and different K_{eff} (grass hedge = 34 mm h^{-1} and row crop area = 5.1 mm h^{-1}) vs. measured sediment yield. Values in parentheses are standard errors of parameter estimates.

slope of 1.16. The error prediction plot (predicted minus measured sediment yield using uniform K_{eff}) illustrates overprediction of measured sediment yield for events producing less than 2 Mg ha^{-1} and an event greater than 7.5 Mg ha^{-1} (fig. 7), although these prediction errors are probably heteroskedastic. It is noteworthy that at zero measured sediment yield, substantial sediment yield (greater than 4 Mg ha^{-1}) was predicted by the uniform K_{eff} parameter for two events (fig. 7). Error values for sediment yield were all within 5 Mg ha^{-1} (fig. 7).

Predicted sediment yield using nonuniform K_{eff} values agreed somewhat better with measured sediment yield. The model efficiency improved from 0.51 to 0.72. This is a 40% increase in model efficiency. However, the coefficient of determination did not improve. The condition with nonuniform K_{eff} values slightly underpredicted sediment yield with a regression slope of 0.92.

The watershed channels (channels 1, 3, and 4) may have contributed to a significant decrease in runoff and sediment yield leaving the watershed because of the high K_{eff} (34.0 mm h^{-1}), low slope gradient (<1% for channels 3 and 4), and perennial grasses. The lower slope gradient in the channel along with perennial grasses appears to assist in decreasing the runoff velocity, allowing more time for deposition and infiltration. The high K_{eff} in the channels increases infiltration and enhances deposition of detached soil particles. This in turn reduces runoff and sediment leaving the watershed.

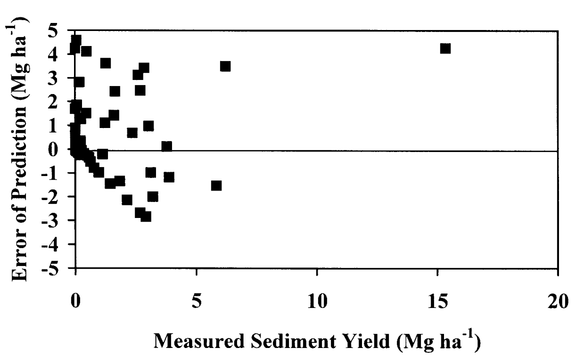

Figure 7. Error of prediction (predicted minus measured sediment yield) using uniform K_{eff} vs. measured sediment yield by event.

Conclusions

The WEPP watershed model was used to simulate runoff and sediment yield from a 6.6 ha watershed of the USDA-ARS National Soil Tilth Laboratory Deep Loess Research Station near Treynor, Iowa. The objectives of this study were to evaluate the performance of the WEPP watershed model in simulating the grass hedge specific effects of sediment trapping (TE), bench terracing (BT), and changes in soil hydraulic conductivity (HC) on simulated hillslope runoff and sediment yield, and to model the effects of measured effective hydraulic conductivity (K_{eff}) values from a grass hedge management system by comparing predicted runoff and sediment yield values to those measured in a small watershed over an 11-year period.

For the first objective, the WEPP watershed model was used to simulate the individual effects of bench terracing, sediment trapping, and changes in soil hydraulic conductivity as affected by the grass hedges. The highest reduction in simulated sediment yield was from the individual effect of bench terracing (58%), followed by sediment trapping (36%) and hydraulic conductivity (1%). Bench terracing was also found to be the most significant effect in simulating runoff reduction (9%), followed by soil hydraulic conductivity (7%) and sediment trapping by grass hedges (3%). Combination of all three effects gave the highest reduction in runoff (22%) and sediment yield (79%) as compared to individual effects or a combination of two effects. The model showed little response from changing the spacing of grass hedges.

For the second objective, the WEPP model gave reasonable results on runoff prediction compared with measured data, with a coefficient of determination (r^2) of 0.78 and a model efficiency (ME) of 0.70 when using measured soil hydraulic conductivity for the grass hedge, row crop, and channel areas. The model overpredicted runoff (regression slope = 1.23) when uniform soil hydraulic conductivity for the grass hedge, row crop, and channel areas was used. Sediment yield was slightly underpredicted (regression slope = 0.92) when measured K_{eff} values for grass hedge, row crop, and channel areas were used in the WEPP simulations. Using uniform K_{eff} overpredicted sediment yield, with a regression slope equal to 1.16. Therefore, it is suggested that measured data of saturated hydraulic conductivity for grass hedge, row crop, and channel areas be included for runoff and sediment yield predictions. It is noted that WEPP has some challenges with predicting realistic soil loss for hedge systems installed on the hillslope. Future work addressing this issue is needed.

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